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Analysis of the Climate Vulnerability of Summer Vegetable-Producing Households in the Trishuli-Narayani River Corridor, Nepal

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Abstract

The impact of climate change on agricultural livelihoods is significant, particularly for summer vegetable growers in the Trishuli-Narayani River corridor of Nepal, which includes the Chitwan, Dhading, and Nuwakot districts. A survey was conducted with 300 farmers—100 from each district—using vulnerability assessment tools that included 57 indicators: 18 for exposure, 17 for sensitivity, and 21 for adaptive capacity. Finally, principal component analysis was performed with normalized data to assess vulnerability across districts. Our study revealed significant variations in vulnerability. Chitwan exhibited moderate vulnerability (index range: -4.9 to +5.8) because of better access to resources and infrastructure, enhancing its adaptive capacity. Dhading faced greater vulnerability (-5.7 to +7.1) because of a combination of high exposure to climate hazards and lower adaptive capacity. However, in Nuwakot, it was found an extended range of vulnerability indices (-4.2 to +7.3) among summer vegetable farmers. The above results summarize the need for specific interventions in each district. Dhading, with a high number of vulnerable farmers, may require more significant support in allocating resources and capacity building. The Nuwakot district should focus on addressing internal disparities and ensuring access to resources and infrastructure development for all farmers. This study highlights the importance of localized, context-specific adaptation plans to support the resilience of agricultural communities facing climate risks. This underscores the effectiveness of a multidimensional vulnerability assessment approach in agricultural contexts. Future research could explore the most effective methods for capacity strengthening and investigate ways to encourage the adoption of climate-resilient cultivation practices.

Keywords

Adaptive capacity; Adaptation strategies; Vulnerability index

Introduction

Climate change is one of the major risks of the world, particularly in developing countries such as Nepal, which affects farming communities that heavily depend on natural resources and hence threatens their livelihoods (Gum *et al.*, 2009; Uprety *et al.*, 2017; Yang *et al.*, 2021). Climate change effects have already been observed in Nepal and are anticipated to increase further in the upcoming years. Agriculture, a major economic sector of Nepal, is highly vulnerable to climate change. Among different crops, summer vegetables play an important role in the economy and food security of farmers in Nepal (IPCC, 2022). Changing climate patterns drastically affect, causing altered growth cycles, increased pest infestations, and reduced yields of summer vegetables (Potop *et al.*, 2014). A major study by Phuyal (2013) suggested the urgency of understanding and enhancing the adaptive capacity of summer vegetable growers against climate change.

According to the sixth assessment report, climate change is already disturbing agricultural practices with shifts in temperature, fluctuation in precipitation levels, and the disturbances in frequency and magnitude of extreme climatic events around the globe (IPCC, 2022). Hence, new adaptation and mitigation strategies are essential to secure food security and sustainable livelihoods for farmers (Nelson *et al.*, 2010). In Nepal, the situation is more disturbing due to the country's diverse terrain and climatic conditions (Phuyal, 2013). While developing and implementing adaptation measures it is important to address the site-specific problems and climate vulnerabilities to mitigate emerging climatic issues, enhancing adaptive capacity and climate resilience (Burton *et al.*, 2006; van Aalst *et al.* 2008) but depending on biophysical indicators, such as exposure and sensitivity only to measure vulnerability could lead to misleading policy implications (Piya *et al.*, 2012).

The IPCC defines vulnerability as the tendency to be adversely affected by climate change with three key dimensions considered; e.g. exposure (i.e. the degree of system exposure to climate hazards), sensitivity (i.e. susceptibility to climate-induces challenges), and adaptive capacity (i.e. the system's ability to adjust to climate change) (IPCC, 2022). Understanding these three dimensions is very important to develop effective climate adaptation strategies for farmers. Different studies have earlier emphasized the importance of local knowledge, resource management, and infrastructural improvements in enhancing resilience as well (Malla, 2008). Such information helps policymakers to identify effective measures, optimize resource allocation, and encourage sustainable practices (Rezvani *et al.*, 2023). Frequent fluctuations in temperature, erratic precipitation, and extreme weather events are observed in the different parts of Nepal e.g. Chitwan, Dhading, Nuwakot, etc. (Shrestha and Aryal, 2011). Variations in the adaptive capacity, exposure to climate risks, and sensitivity to agricultural practices significantly influence overall vulnerability to climate change affecting the livelihood of summer vegetable growers in these districts (Gautam *et al.*, 2013).

Thus, this study aimed to find out the adaptive capacity of summer vegetable growers to climate change in the Trishuli-Narayani River corridor of Chitwan, Dhading, and Nuwakot which were recognized as highly vulnerable to floods, unpredictable rainfall patterns, and prolonged droughts. Though there were certain limitations, our focus was to understand how demography, economy, and social factors influence the adaptive capacity of vegetable farmers. The null hypothesis of the study was said as none of the socioeconomic, political, demographic, institutional or environmental factors affect the vulnerability through adaptive capacity, exposure and sensitivity. The objective of the study was to assess the climate change vulnerability of summer vegetable growers in different study districts in absolute and relative contexts. By thoroughly evaluating those factors with a methodological framework incorporating a comprehensive set of indicators of adaptive capacity, exposure, and sensitivity, this study will provide insights into the adverse effects of climate change and which are key contributing factors to their vulnerability. This comprehensive analysis aimed to assist policymakers and stakeholders, providing insights to develop climate resilience in the region.

Methodology

With the help of primary-level data generated from household surveys among summer vegetable growers, a vulnerability analysis of each household was done. Principal Component Analysis (PCA) was used to calculate vulnerability indices for each household with the help of normalized indicators of exposure, sensitivity and adaptive capacity and finally, vulnerability categorization was done.

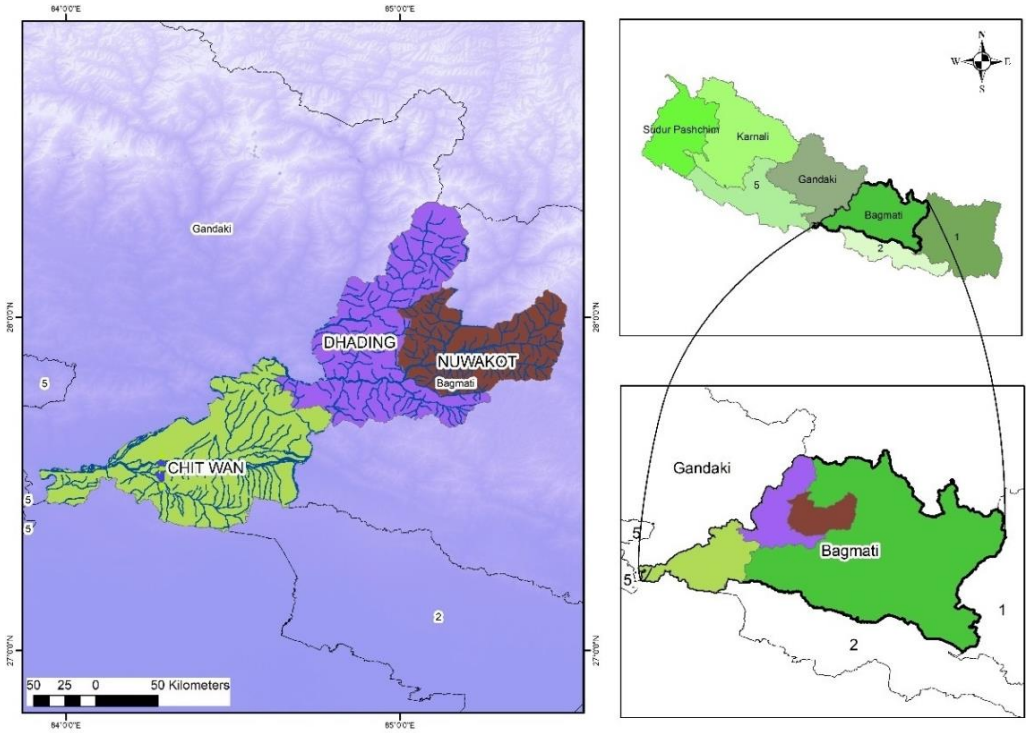

Figure 1: Map of Nepal showing research area in Bagmati Province: Chitwan, Dhading, and Nuwakot

Description of the Study Area

The study was carried out within the Trishuli-Narayani River Corridor of Chitwan, Dhading, and Nuwakot districts, which were chosen due to their high vulnerability to climatic hazards affecting summer vegetable growers. Chitwan district is located in the lowlands (27.61°N, 84.88°E), Dhading district is in the mid-hills (27.90°N, 85.19°E), and Nuwakot district is extended up to the high hills (27.68°N, 85.42°E). This variation in elevation, ranging from roughly 27.61°N to 27.90°N latitude and 84.88°E to 85.42°E longitude, plays a role in the climatic vulnerabilities experienced by farmers (Dandekhya *et al.*, 2017; Luitel *et al.*, 2020; Rai *et al.*, 2022). These areas have distinctly different geographical and climatic conditions, making them suitable for studying the differences in impacts of climate change on summer vegetable farming.

Sample Size and Sampling Techniques

Summer vegetables production area from Chitwan district i.e. Sisai/Sisabazar/Meghauli, Haraiya/Saranpur and Chaukidada/Biretar/Kusumtar, from Dhading district i.e. Benighat, Galchhi and Gajuri, and Nuwakot district i.e. Bidur and Belkot were identified along the Trishuli Narayani River corridor with the help of Agriculture Development Office (ADO) of the respective district. ADO is a district-level authorized government organization assigned for extension and agricultural policy-level work at the ground level. Members from groups of farmers including small, medium, marginalized etc were identified with the help of ADO. The simple random sampling technique was used to finalize 100 summer vegetable growers from each district from a list of summer vegetable growers provided by the respective Agriculture Development Office (ADO) of each district, with 300 growers in total. A pre-tested questionnaire was used for the household survey to collect the primary information for vulnerability analysis.

Indicators for Vulnerability

Vulnerability to climate change is generally influenced by various factors. Indicators for exposure, sensitivity, and adaptive capacity were selected based on the theoretical frameworks. Indicators for the exposure included temperature change, precipitation patterns, the number of extreme weather events, etc. The sensitivity indicators focused on the impacts of climate-related disasters on livelihoods. Adaptive capacity indicators were developed from the IPCC livelihoods framework and household assets such as physical, human, natural, financial, social capital, etc. were considered as indicators (IPCC, 2007; Nelson *et al.*, 2010).

Indicators for Adaptive Capacity

The indicators in Table 1 provide a comprehensive view of the adaptive capacity of summer vegetable growers in Chitwan, Dhading, and Nuwakot. These indicators cover various aspects, such as demographic information, educational level, income sources, land ownership, and access to resources.

Table 1: Indicators for adaptive capacity used in vulnerability assessment among summer vegetable growers in research areas

Component for adaptive capacity	*Indicators*	*Description of the indicators*	*Unit*
Location	Dhading dummy	Residents of the study area compared to Dhading district	Dummy (1 if resident, 0 otherwise)
Location	Nuwakot dummy	Whether the household is from Nuwakot district	Dummy (1 if from Nuwakot, 0 otherwise)
Education	No years of education	Household head's ability to read and write	Years
Demographics	Household head age	Age of the household head	Years
Demographics	Household head sex	Sex of the household head	Male/Female
Demographics	Ethnic category	Ethnic group of the household head	Categorical
Household size	No Household members	Total number of people in the household	Count
Migration	Migrant members of the home	Number of household members living elsewhere	Count
Income diversification	Income from non-agriculture source	Income from sources other than agriculture (Nepalese rupees)	NRs (thousands)
Agricultural experience	Experience in agriculture	Number of years involved in agriculture	Years
Experience in vegetable	Experience in summer vegetable farming	Number of years involved in vegetable farming	Years
Land ownership	Land ownership	Amount of land owned by the household	Kattha (0.0126 ha)
Land use	Area coverage by vegetable	Area of land used for summer vegetables	Kattha (0.0126 ha)
Food security	Food sufficiency	Whether the household produces enough food for itself	Yes/No
Climate change awareness	Knowledge of climate change	Whether the household is aware of climate change	Dummy (1 if aware, 0 otherwise)
Pest management	Beneficial insects seen on the farm	Increase in the number of beneficial insects	Count
Access to services	Access to extension services	Whether the household receives agricultural extension services	Dummy (1 if receives services, 0 otherwise)
Access to information	Access to communication	Whether the household has access to communication services	Dummy (1 if has access, 0 otherwise)
Access to finance	Access to credit	Whether the household has access to credit services	Dummy (1 if has access, 0 otherwise)

Component for adaptive capacity	*Indicators*	*Description of the indicators*	*Unit*
Training	Training number	Number of trainings received on climate change adaptation	Count
Social capital	Involvement in cooperatives	Whether the household participates in cooperatives	Dummy (1 if participates, 0 otherwise)

Indicators for Exposure

The indicators for exposure were selected based on the hypothesis that a higher rate of change in temperature and precipitation, as well as a higher frequency of floods, droughts, and hailstorms, would signify higher exposure to climate change and severe weather conditions. Table 2 presents indicators of exposure to climate change for summer vegetable growers in Chitwan, Dhading, and Nuwakot. These indicators are essential for understanding the extent to which farmers are exposed to various climate-related events and their impacts on their agricultural practices. These exposure indicators highlight the challenges faced by farmers in the study area and underscore the urgent need for adaptive strategies and resilience-building measures.

Table 2: Indicators for exposure used in vulnerability assessment among summer vegetable growers in research areas

Component for exposure	*Indicators*	*Description of the indicators*	*Unit*
Crop disease	Notice of changes in the Field with new diseases	Increase in the number of new diseases	Dummy (1 if increased, 0 if not)
Insect pest	Notice of changes in the field with new insects	Increase in the number of new insects	Dummy (1 if increased, 0 if not)
Weeds	Notice of changes in the field with new weeds	Increase in the number of new weeds	Dummy (1 if increased, 0 if not)
Pollinators	Notice a decrease in pollinators	Decrease in the number of pollinators	Dummy (1 if decreased, 0 if not)
Income Impacts	Have IPA changed	Effect of climate change on income per unit area	Dummy (1 if increased, 0 if not)
Market impacts	CC effect on market prices	Change in market prices due to climate change	Dummy (1 if increased, 0 if not)
Summer temperature	Increase in summer temperature	Increase in average summer temperature	Dummy (1 if increased, 0 if not)
Hot days	Increase in hot days	Increase in the number of hot days	Dummy (1 if increased, 0 if not)
Delayed precipitation	Delay in monsoon	Delay in the arrival of the monsoon season	Dummy (1 if delayed, 0 if not)
Intensity of precipitation	Increase in intensity of summer rainfall	Increase in summer rainfall intensity	Dummy (1 if increased, 0 if not)
Frequency of precipitation	Increase in frequency of summer rainfall	Increase in the number of summer rainfall events	Dummy (1 if increased, 0 if not)
Duration of precipitation	Increase in summer rainfall	Increase in summer rainfall events	Dummy (1 if increased, 0 if not)

Component for exposure	*Indicators*	*Description of the indicators*	*Unit*
Droughts	Increase in droughts	Increase in the number of droughts in the past 10 years	Dummy (1 if increased, 0 if not)
Water availability	Decrease in water level	Decrease in water table level	Dummy (1 if decreased, 0 if not)
Floods	Frequency of floods	Number of floods in the last 10 years	Count
Droughts	Frequency of droughts	Number of droughts in the last 10 years	Count
Windstorms	Frequency of windstorms	Number of windstorms in the last 10 years	Count
Landslides	Frequency of landslides	Number of landslides in the last 10 years	Count

Indicators for Sensitivity

Sensitivity points out the extent to which a system is influenced by climate-related factors. The indicators for sensitivity were selected to reflect the livelihood impacts of climatic disasters. The hypothesis is that greater impacts, such as deaths and losses of land, livestock, and crops, would indicate greater sensitivity to such events. Table 3 presents indicators of sensitivity to climate-related stimuli among summer vegetable growers in Chitwan, Dhading, and Nuwakot. These indicators focus on factors such as water availability, irrigation sources, and the physical features of the land. Farmers' sensitivity to climate-related stimuli is influenced by factors such as distance from rivers and irrigation canals. The availability of facilities such as irrigation channels, tube wells, and ponds also affects sensitivity.

Table 3: Indicators for sensitivity used in vulnerability assessment among summer vegetable growers in research areas

Component for sensitivity	*Indicators*	*Description of the indicators*	*Unit*
Male children in the household	Below 15 years male	Number of male children under 15 years old	Count
Female children in the household	Below 15 years female	Number of female children under 15 years old	Count
Male adults in the household	Above 60 years male	Number of male household members over 60 years old	Count
Female adults in the household	Above 60 years female	Number of female household members over 60 years old	Count
Livelihood source	Agriculture as the primary source of income	Whether agriculture is the main source of income for the household	Dummy (1 if primary source, 0 otherwise)
Income impacts	Income from agriculture	Income generated from agriculture (Nepalese rupees)	NRs (thousands)
Land loss	Land damaged by climate hazards	Amount of land damaged by climate hazards	Kattha (0.0126 ha)
Crop loss	Crops damaged	Amount of crops damaged by climate hazards	Quintal

Livestock loss	Animal died	Number of animals lost due to climate hazards	Count
Access of river	Distance from river	Distance from the nearest river	Kilometres
Access to an irrigation canal	Distance from an irrigation canal	Distance from the nearest irrigation canal	Kilometres
Access of irrigation	Facility of irrigation	Whether the household has access to irrigation	Dummy (1 if has access, 0 otherwise)
River for irrigation	The facility of the river for irrigation	Uses river water for irrigation	Dummy (1 if used, 0 otherwise)
Borehole for irrigation	Facility of borehole	Uses borehole water for irrigation	Dummy (1 if used, 0 otherwise)
Irrigation channel	Facility of irrigation channel	Uses irrigation canal water for irrigation	Dummy (1 if used, 0 otherwise)
Tube well for irrigation	The facility of tube well	Uses tube well water for irrigation	Dummy (1 if used, 0 otherwise)
Pond for irrigation	Facility of pond	Uses pond water for irrigation	Dummy (1 if used, 0 otherwise)

Data Analysis

The data were normalized and then it was used to calculate indices of adaptive capacity, exposure and sensitivity. After that, the vulnerability indices were calculated for each household of summer vegetable farmers (IPCC, 2007; Lien, 2019). Suitable indicators were taken and normalized via the following formula provided.

Normalized value = (Observed value - Mean)/Standard deviation of the indicators

The data were subsequently analyzed via descriptive statistics, and indices for adaptive capacity, exposure, and sensitivity were calculated. Principal component analysis (PCA) was applied to assign weights to the identified indicators. The first Eigenvalue scores obtained from PCA were used as a weight for vulnerability analysis in the study. The indices were calculated via the following formula.

$$I_j = \sum_{i=1}^{k} b_i \left(\frac{a_{ji} - x_i}{s_i}\right)$$ - Equation 1

Where,

i = respective value of index

b = loadings from the first component from PCA (PCA1) taken as weights for the respective indicators

a = indicator value

x = mean indicator value

s = standard deviation of the indicators

The vulnerability indexes for each household were then calculated using Equation 2 given below.

$$V = E + S - AC$$ - Equation 2

Where,
V = Vulnerability index,
E = Exposure index,
S = Sensitivity index and
AC = Adaptive capacity index for the respective household

Results

Descriptive Characteristics of Adaptive Capacity, Exposure, and Sensitivity

Table 4 describes the various indicators of adaptive capacity, exposure, and sensitivity among summer vegetable growers in Chitwan, Dhading, and Nuwakot.

Adaptive Capacity Indicators

The average age of the household heads was 49.72 years old, indicating a mature population of summer vegetable growers. Households had been engaged in agriculture for an average of 22.01 years, specifically in summer vegetable farming, for 17.13 years. The average landholding area was 16.04 hectares, with 4.09 hectares dedicated to summer vegetables. Only 15% of the households relied primarily on agriculture for their income. However, 68% were aware of climate change, and 85% had access to communication services. Involvement in the cooperatives was moderate, with 76% of the households involved among respondent vegetable growers.

Exposure Indicators

Farmers reported significant changes in field conditions due to climate-related events. These included increases in new diseases, insects, and weeds. A notable decrease in pollinators and an increase in beneficial insects were observed, indicating ecosystem changes. Over the past 10 years, the frequency of floods and droughts has been notably high, averaging 2.07 floods and 3.86 droughts, respectively.

Sensitivity Indicators

Sensitivity to climate-related stimuli is influenced by water availability, irrigation sources, and topography. Farmers were, on average, 1.86 kilometres away from rivers and 0.33 kilometres from irrigation canals. Approximately 55% of the farmers reported a lack of water sources, impacting crop production. However, 71% had access to irrigation facilities, with 23% using rivers and 13% using boreholes for irrigation. On average, 5,334.18 hectares of land were damaged by climate hazards, with crop losses averaging 93,883.33 tons. Additionally, an average of 7.85 animals died due to climate hazards.

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Table 4: Descriptive characteristics of the adaptive capacity, exposure and sensitivity of summer vegetable growers in the research areas

Indicators	*Avg (Std)*	*Indicators*	*Avg (Std)*	*Indicators*	*Avg (Std)*
Adaptive Capacity					
Dhading dummy	0.33 (0.47)	Nuwakot dummy	0.33 (0.47)	No. of years of education	6.80(3.79)
Age of HH	49.72 (14.74)	Sex of HH	0.17 (0.37)	Ethnic Category	0.55 (0.49)
No. of HH members	6.01 (2.75)	HHM staying away from home	0.67 (1.38)	Income from non-agriculture (in thousands)	183.36 (317.46)
Experience in agriculture	22.01 (11.77)	Experience in summer vegetable production	17.13 (9.61)	Own land holding	16.04 (15.68)
Area of vegetable	4.09 (4.26)	Food sufficiency	0.19 (0.39)	Knowledge of CC	0.68 (0.46)
Beneficial insects on farm	0.33 (0.47)	Access to ext. service	0.66 (0.47)	Assess to communication	0.85 (0.35)
Access to credit	0.51 (0.50)	Training number	0.55 (1.03)	Involvement in cooperatives	0.76 (0.42)
Exposure					
Change in field new disease	0.81 (0.38)	Change in field new insect	0.79 (0.40)	Appearance of new weeds	0.58 (0.49)
Notice a decrease in pollinators	0.67 (0.46)	Have IPA changed	0.69 (0.46)	CC effect on market prices	0.22 (0.41)
Increase in summer temp	0.75 (0.42)	Increase in hot days	0.73 (0.44)	Delay in monsoon	0.7 (0.45)
Increase in intensity of summer rainfall	0.63 (0.48)	Increase in frequency of summer rainfall	0.63 (0.48)	Increase in summer rainfall	0.64 (0.47)
Increase in drought	0.71 (0.45)	Decrease in water level	0.66 (0.47)	Frequency of flood	2.07 (3.17)
Frequency of drought	3.86 (2.87)	Frequency of hailstorm	2.50 (1.98)	Frequency of windstorm	3.01 (2.23)
Frequency of landslides	1.25 (2.24)				
Sensitivity					
Below 15 yrs male	0.69(0.77)	Below 15 yrs female	0.66 (0.84)	Sixty years above male	0.33(0.48)
Sixty years above female	0.32 (0.50)	Agriculture as a primary income	0.84 (0.36)	Income from Ag in _000	228.83 (137.69)
Land damaged by climate hazards	5334.18 (92375.99)	Crops losses	93883.33 (226985.97)	Animal died	7.85 (64.38)
Distance from river	1.86 (1.63)	Distance from an irrigation canal	0.33 (0.36)	Facility of irrigation	0.71 (0.45)
The facility of the river for irrigation	0.23 (0.42)	Facility of boring	0.13 (0.34)	Facility of irrigation channel	0.54 (0.49)
Facility of tube	0.16 (0.37)	Facility of pond	0.050.21)		

Indices of Adaptive Capacity of Chitwan, Dhading and Nuwakot

The adaptive capacity among summer vegetable farmer respondents varied across the research area (Figure 1), which demonstrated the level of differences in adaptive capacity among these districts.

Farmers from Chitwan presented a broader range of adaptive capacity, from approximately -2.5 to -6.2. This wide range indicates a mix of challenges and successful adaptation strategies among farmers. In Dhading, the range of adaptive capacity was narrower, from approximately -4.2 to -2.8, with predominantly negative values. This suggests significant obstacles to adaptation in Dhading. Like Dhading, Nuwakot had a narrower range, from approximately -1.9 to -3.1. This range indicates both challenges and successes in the farmers' ability to adapt.

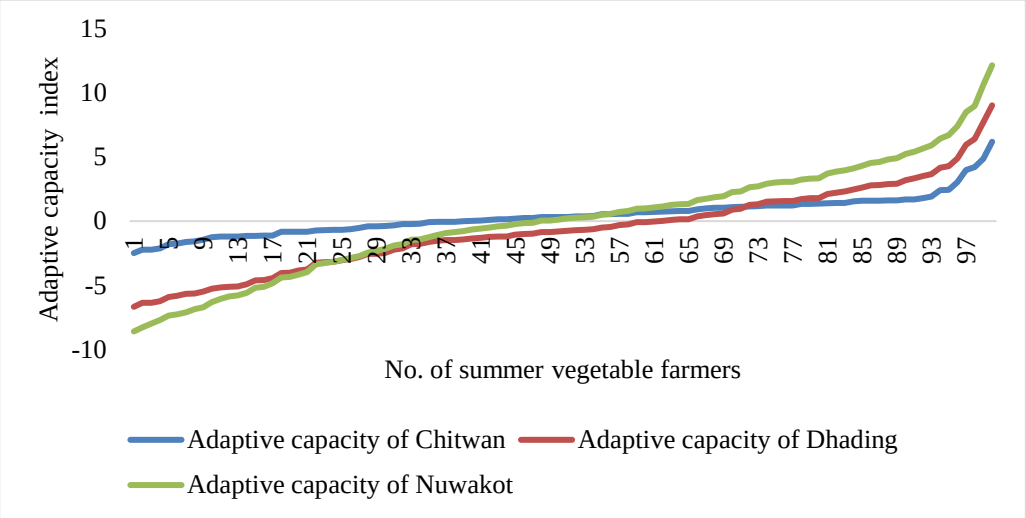

Figure 1: Adaptive capacity index of summer vegetable growers in the research area

Exposure Indices of Chitwan, Dhading and Nuwakot

The exposure index of summer vegetable growers in the research areas delineated the degree of vulnerability to various environmental stressors and socioeconomic factors (Figure 2). The exposure index of Chitwan ranged from approximately -2.5 to -2.3, reflecting a spectrum of challenges and potential opportunities. Dhading exhibited a wider range, ranging from nearly -6.0 to 2.6, indicating potentially heightened vulnerability among farmers. Nuwakot displayed a broad range, from approximately -5.3 to -3.0, highlighting the diverse exposures that farmers face.

Negative values suggest greater susceptibility to adverse conditions, whereas positive values imply resilience or less vulnerability. The data underscore the intricate interplay of factors impacting farmers' livelihoods, emphasizing the need for targeted interventions and adaptive strategies to mitigate risks and enhance resilience in the face of evolving environmental and socioeconomic dynamics. Exposure indicators, such as temperature fluctuations and extreme weather events, significantly impact vulnerability.

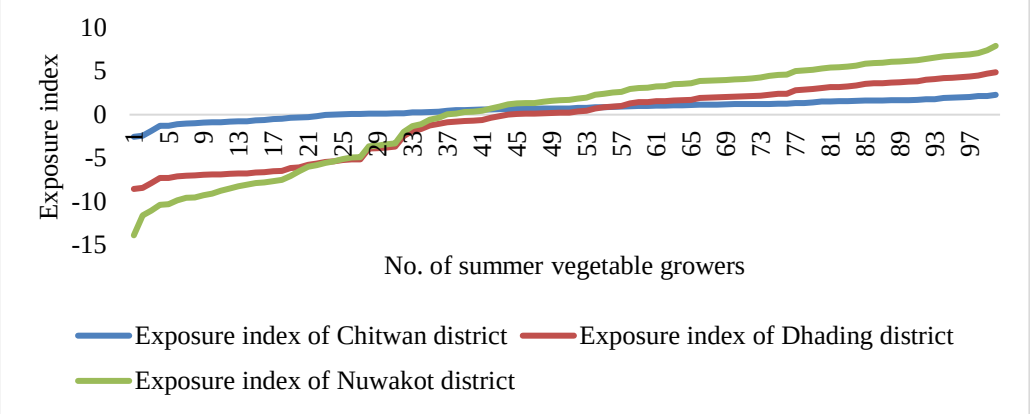

Figure 2: Exposure indices of summer vegetable growers in the research areas

Sensitivity Indices of Chitwan, Dhading and Nuwakot

The sensitivity index among summer vegetable growers in the Chitwan, Dhading, and Nuwakot districts provides insights into their susceptibility to various stressors and changes in environmental and socioeconomic conditions. In Chitwan, the sensitivity score ranged from approximately -2.9 to +3.2, indicating a spectrum of sensitivities among farmers, with some experiencing greater vulnerability than others. Dhading displayed a narrower range, ranging from approximately -3.9 to +2.5, suggesting potentially heightened sensitivity among farmers in this district, with some facing significant challenges. Similarly, in Nuwakot, the sensitivity score ranged from approximately -2.8 to +3.6, highlighting diverse levels of sensitivity among farmers, with some exhibiting greater vulnerability to external factors. Negative values indicate greater sensitivity, whereas positive values suggest lower vulnerability or resilience. The data underscore the complex interplay of factors influencing farmers' sensitivity and emphasize the importance of targeted interventions and support mechanisms to increase resilience and mitigate risks in agricultural communities. The sensitivity indicators, which focus on the livelihood impacts of climate-related disasters, highlight the importance of the local context in vulnerability assessments.

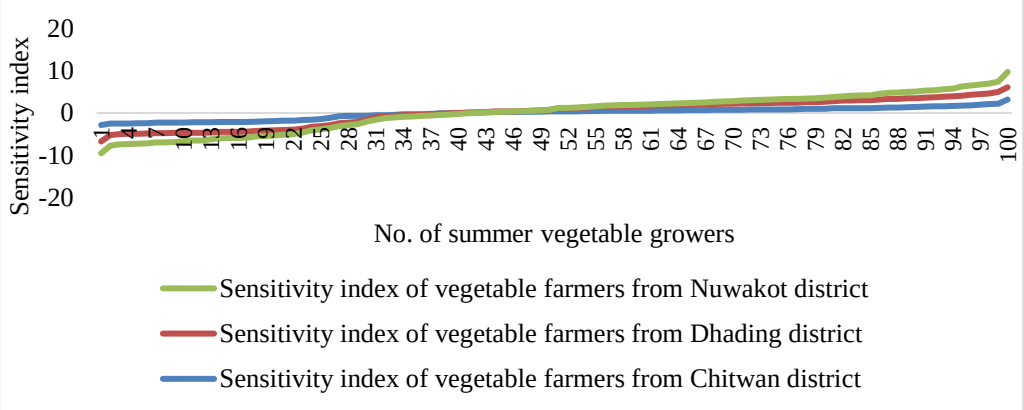

Figure 3: Sensitivity index of the summer vegetable growers in the research area

Vulnerability Indices of Chitwan, Dhading and Nuwakot

Building on the concepts of exposure, sensitivity, and adaptive capacity discussed earlier, the vulnerability indices among summer vegetable growers in the Chitwan, Dhading, and Nuwakot districts provide a measure of their susceptibility to various risks and stressors, encompassing both socioeconomic and environmental factors. Figure 4 visually shows the distribution of the range of vulnerability indices among the vegetable growers in the research areas.

In Chitwan, the vulnerability index among summer vegetable growers ranged from approximately -4.9 to +5.8, indicating a wide scale of vulnerability among them in the district. This range showed that some farmers faced higher risk, and others experienced relatively lower vulnerability. Similarly, in Dhading, the vulnerability index ranged from approximately -5.7 to +7.1. This suggested that farmers in this district may experience even higher extremes in vulnerability, with some facing considerable challenges to their livelihoods, whereas others are more resilient to the impacts caused. Whereas, in Nuwakot, the vulnerability index ranged from approximately -4.2 to +7.3, again highlighting diverse levels of vulnerability among summer vegetable farmers. Some farmers in Nuwakot presented high susceptibility to external factors and changes, whereas others showed a greater capability to fight these conditions. Negative signs with the vulnerability index indicated higher vulnerability, suggesting that the farmers were more susceptible to adverse conditions and positive signs suggested lower susceptibility or higher resilience among farmers. These data suggested the need for targeted interventions and support mechanisms to increase resilience and mitigate risks, thereby improving the livelihoods of summer vegetable farmers in three districts. The varying vulnerability indices among farmers in the three districts highlighted the significant influence of geographic and climatic diversity.

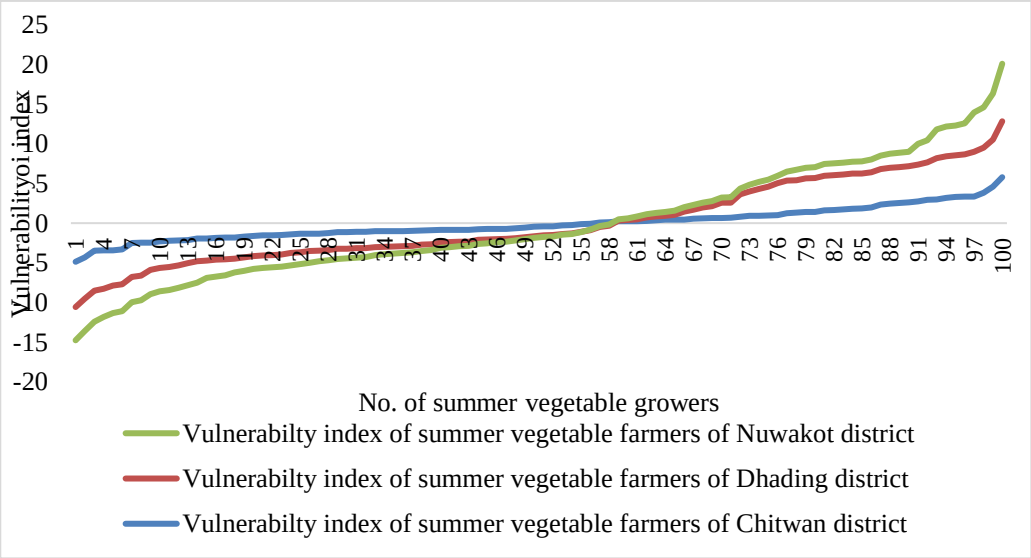
25
20
15
10
5
0
-5
-10
-15
-20
Vulnerabilityoi index
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82 85 88 91 94 97 100
No. of summer vegetable growers
Vulnerabilty index of summer vegetable farmers of Nuwakot district
Vulnerabilty index of summer vegetable farmers of Dhading district
Vulnerabilty index of summer vegetable farmers of Chitwan district

Figure 4: Vulnerability indices of summer vegetable growers in the research areas

Vulnerability Spectrum among Summer Vegetable Growers

Table 5 provides an overall snapshot of the vulnerability assessment conducted on 300 summer vegetable growers from three districts in Nepal i.e. Chitwan, Dhading, and Nuwakot. The data revealed a diverse range of vulnerability levels among these farmers, as measured by a vulnerability index that considers both socioeconomic and environmental factors. In Chitwan, 31% of the farmers fall under the "highly vulnerable" category, indicating significant challenges. However, a contrasting 46% are classified as "less vulnerable," suggesting a wider spectrum of vulnerability compared with other districts. The average vulnerability index for Chitwan is -0.11, placing it in the "slightly vulnerable" category. The standard deviation of 4.71 signifies a moderate spread of vulnerability scores within the district. In Dhading, the highest proportion (41%) of farmers were categorized as "highly vulnerable," highlighting that a potentially larger population faces critical challenges. The average vulnerability index in Dhading is 0.09, which is closer to the average vulnerability level. However, the standard deviation of 5.71 indicates a wider range of vulnerability scores than Chitwan does. In Nuwakot, 31% of the farmers were classified as "highly vulnerable", and 47% were classified as "less vulnerable." The average vulnerability index for Nuwakot is -0.10, suggesting slight vulnerability. The standard deviation of 7.30 reveals the highest spread of vulnerability scores among the three districts.

Table 5: Vulnerability categorization due to climate change of summer vegetable growers in the research areas

District	*Highly vulnerable (%)*	*Moderately vulnerable (%)*	*Less vulnerable (%)*	*Average vulnerability index*	*Standard deviation*
Chitwan	31	23	46	-0.11	4.71
Dhading	41	18	41	0.09	5.71
Nuwakot	31	22	47	-0.10	7.3

Discussion

In our study, we determined the range of different vulnerability experiences of summer vegetable growers in three different districts. Each district, with its problems and opportunities, has a different range of vulnerability indices, and farmers are tackling these indices in a specific way. Vulnerability indices ranged from -4.9 to +5.8 in Chitwan district, from -5.7 to +7.1 in Dhading district and -4.2 to +7.3 in Nuwakot district among identified summer vegetable farmers for this study purpose. Vulnerability assessment tools were applied where principal component analysis was performed generating an index ranging from -10 to +10 with -10 denoting highly vulnerable and +10 as the least vulnerable due to climate change and associated parameters. The study may not fully include all the dimensions of vulnerability, i.e. qualitative aspects like cultural practices or social networks, which may also influence adaptive capacity.

In Chitwan, among summer vegetable growers, strong adaptive capacity was found, which is due to better access to different resources and infrastructures which is similar as reported by Regmi *et al.* (2010), who emphasized the importance of resource availability for climate-resilient agriculture. Different interventions should be done to address the varied level differences in resources and support among farmers across different places, hence facing significant obstacles to adaptation. Paudel *et al.* (2014) also suggested the need for a similar level of interventions in their research areas as well. It was found that Nuwakot should focus on improving the accessibility of resources and infrastructure to mitigate the impacts of climate change. Also in Chitwan and Dhading as well, it was found that different socioeconomic factors significantly affect the functional access to existing resources like climate information services which are useful tools to strengthen the adaptation capacity (Bajracharya *et al.*, 2023; Rai *et al.*, 2022).

Tiwari *et al.* (2014) identified those key challenges in their regions as well. Our findings also uphold the results of Adhikari *et al.* (2015). They also reported different vulnerability levels across different districts and the nature of vulnerabilities varies, reflecting the unique nature of each region. In similar research in the central part of Nepal, it was found that low resources, inadequate income, and finally food insecurity were the primary causes of vulnerability due to climate change (Giri *et al.*, 2021). To address those challenges, collective efforts by the government offices, different organizations, and residents were important. Enhancing awareness among people, infrastructure development, and access to resources will be crucial in building resilient agricultural communities capable of coping with climate change. Manandhar *et al.* (2011), and Gentle and Maraseni (2012) also highlighted similar importance of those factors in their research areas.

In our study, we found 56.33% of summer vegetable growers among our respondents had a –ve vulnerable coefficient whereas 43.66% of respondents found with +ve vulnerable coefficient. Concerning such information, local bodies, respective Agriculture Development Office (ADO) and other agriculture institutes should intervene. By adopting site-specific interventions, the vulnerability of summer vegetable farmers in all three districts can be significantly reduced. That would improve their livelihoods and resilience against climate-related risks. Adger (2006), Eakin and Luers (2006), and Smit and Wandel (2006) also highlighted the similar importance of building resilience to climate change and its effects on farming. As found in our research areas, at the policy level, especially the local governments are mobilizing natural resources and social capital efficiently so that an adequate supply of adaptation services will be available at the farmers' level in Nepal (Karki *et al.*, 2021). Hence it follows the Local Adaptation Plans of Action (LAPA) and National Adaptation Programme of Action (NAPA) by refining local adaptation strategies and addressing barriers like resource constraints supporting climate-smart agriculture (GoN, 2011) and ecosystem-based adaptation while providing evidence for policy implementation, fostering collaborations, and promoting climate resilient agricultural practices, crop diversification according to Agriculture Development Strategy 2015-2035 (GoN, 2015).

Conclusion

This study analyzed the vulnerability status due to climate change in the Chitwan, Dhading, and Nuwakot districts of Nepal and found distinct variations in vulnerability among vegetable growers from these districts. It was found that Dhading was the most vulnerable district due to its high exposure to climate hazards, lower adaptive capacity, and limited access to different resources to vegetable farmers whereas, Chitwan, with lower vulnerability than Dhading, can be linked with better access to resources and infrastructure, enhancing its resilience to climate change. With this situation, Nuwakot reported a wide range of vulnerability indices reflecting enormous differences among the vegetable growers in the district. Thus, our study revealed that socioeconomic factors among summer vegetable growers affect how they utilize the resources available hence showing there is a need for specific interventions based on the vulnerabilities of each region. With high numbers of vulnerable vegetable growers, Dhading may require more infrastructural support in terms of resources and capacity building and Nuwakot, we should address fair access to resources and infrastructure development as well among all vegetable growers across the district. Policymakers must prioritize resource allocation, capacity-building initiatives, and infrastructure development to mitigate the adverse effects of climate change on vulnerable farming populations at the local level. By addressing these key areas, we can support sustainable agricultural practices in those districts. Our research contributes to a deeper understanding of how climate change impacts the vulnerability of agricultural communities. This study provides a foundation for developing effective adaptation strategies tailored to specific regional needs and these findings underscore the need for integrating localized research into national frameworks to enhance climate resilience in agriculture. Future research could explore the most effective methods for capacity building and investigate ways to encourage the adoption of climate-resilient agricultural practices among vegetable growers.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes
Collected the data	Yes	No	No	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes
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The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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